RESPONSE OF RICE VARIETY TO PLANT SPACING AND NITROGEN FERTILIZATION[1]

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Growing rice with spacings of 22–25 cm between rows and 20–24 cm between hills (56–64 hills per 3.3 m^2) introduced by Iso (1930) and nitrogen application of about 80 kg per ha has been widely accepted as a standard cultural practice in Taiwan during the past three decades. Recently, however, attempt has been made to plant rice more closely and to apply more nitrogen fertilizer in order to obtain higher grain yields. Experimental findings so far obtained are generally encouraging (Chang and Yang, 1965) and the present trend of rice cultivation in Taiwan has been gradually moving toward dense planting and heavy fertilization. Currently, plant spacings of either 24 x 15 cm (90 hills per 3.3m^2) or 27 x 13.5 cm (89 hills per 3.3 m^2) and nitrogen application of about 100 kg per ha are generally recommended. The adoption of this improved cultural practice has already achieved a great yield increase in paddy yields as indicated by the results of so called "integrated demonstration" project initiated in the fall rice crop of 1963 in Taiwan (Huang, 1967).

It has been reported that responses of rice to spacing and nitrogen varied with varieties (Matsuo, 1952) and crop seasons (Tanaka *at al.*, 1964). However. information is still not available regarding the optimum levels of spacings and nitrogen necessary for a given variety to attain a maximum grain yield at a given crop season. An understanding of interactions among varieties, spacings, and nitrogen levels at different crop seasons may be useful to rice workers in their efforts to explore the possibility of further increasing unit yield of rice by dense planting and heavy fertilization. The odjective of this investigation was to determine the responses of two *japonica* rice varieties to four spacing treatments and three nitrogen levels in both the first and the second crops at Chianan area of Taiwan.

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MATERIALS AND METHODS

Six field experiments were conducted during the period from 1965 to 1967 at Tai-tou-ken Farm of the Chiayi Agricultural Experiment Station. The variables included four plant spacings, 3 nitrogen levels, and two rice varieties. Plant spacing were 30 x 20, 30 x 15, 30 x 10, and 30 x 5 cm which gave approximately 55, 73, 110, and 220 hills per 3.3m^2, respectively. These spacings are named as "wide-row and close-hill" spacings because inter-row spacings are kept wide and increased planting densities are obtained through the reduction of intra-row spacings. The nitrogen levels were 80, 120, and 160 kg per ha applied in the form of ammonium sulphate. Calcium superphosphate and potassium sulphate were used as carriers of P_2O_5 and K_2O which were applied both at the rate of 100 kg per ha. Rice varieties used in this trial were Chianung 242, a *japonica* rice variety of panicle weight type, and Tainan 3, the best tillering *japonica* rice variety carrently available in Taiwan, which was selected to represent the panicle number type.

Tai-tou-ken soil is relatively low in fertility, and typical of the soil of this type on the rain-fed plains of Chinan district. The predominant soil type in the experimental area was silty clay loam. The surface soil contained 0.94% organic matter. The available P_2O_5 and K_2O were 145 and 90 kg per ha, respectively. The pH of the surface soil was 6.6.

The field experiment was laid out in a randomized block, split-plot design with four replications. Nitrogen levels made the whole plots whereas factorial combinations of plant spacings and rice varieties comprised the subplots. Subplot size was 1.5 x 6.0 m and consisted of 5 rows. An extra row was included at both sides of the main plots to eliminate border effects.

The whole plots were harvested for yield determination. Besides grain yield, data for components of yield and some traits of agronomic importance were also recorded. A combined analysis of variance was made for grain yield over 3 years in both crops. The orthogonal linear, quadratic, and cubic comparisons were calculated as described by Snedecor (1961). Leaf area at the heading stage was measured in both crops of 1966 and 1967 by the method of Bhan and Pande (1966). Plasticity index was calculated by the formula suggested by Tanaka (1967).

EXPERIMENTAL RESULTS

Effect of Plant Spacing on Grain Yield

The highest yields were obtained by the most close spacing of 30 x 5 cm (Table 1). When averaged over years, nitrogen levels, and varieties, grain yield increased 50, 205, and 338 kg per ha or 0.77, 3.17, and 5.22% in the first crop, and 92, 225, and 303 kg per ha or 1.72, 4.21, and 5.67% in the second one at the spacings of 30×15, 30×10, and 30x5 cm, respctively. The effect of plant spacing on grain yield was highly significant in both crops (Table 2). Variation in spacing effect was due principally to linear regression.

Table 1. Grain yield and density response of 2 rice varieties, 1965–1967.

Variety	Spacing (cm)	Grain yield (kg/ha)		Density response (increage in kg/ha)		Density response (% increase)	
		First crop	Second crop	First crop	Second crop	First crop	Second crop
Chianung 242	30×20	6,287	5,135	—	—	—	—
	30×15	6,189	5,173	−98	38	− 1.56	0.74
	30×10	6,463	5,276	176	141	2.80	2.74
	30× 5	6,611	5,380	324	245	5.15	4.77
Tainan 3	30×20	6,661	5,556	—	—	—	—
	30×15	6,860	5,704	199	148	2.99	2.66
	30×10	6,896	5,865	235	309	3.53	5.56
	30× 5	7,012	5,918	351	362	5.27	6.52
Average of 2 varieties	30×20	6,474	5,346	—	—	—	—
	30×15	6,524	5,438	50	92	0.77	1.72
	30×10	6,679	5,571	205	225	3.17	4.21
	30× 5	6,812	5,649	338	303	5.22	5.67

There was no significant variety x spacing interactions in both crops (Table 2). The grain yields of both varieties generally increased with the decrease in plant spacing. The degree of varietal response to spacing was essentially the same, since plasticity indices for both varieties at various spacings were quite similar in both crop seasons (Table 3). The year x spacing, and year x spacing x variety interactions were not significant. Apparently, varietal responses to spacing varied slightly with years in both crops.

Table 2. Analysis of yield variance for combined 1965–1967 data.

Source of variation	D.F.	First crop		Second crop		LSD	
		M. S.	F.	M. S.	F.	5%	1%
Year	2	36,910,935	106.64**	18,629,990	53.80**	3.55	6.01
Nitrogen levels	2	34,437,223	99.49**	5,440,183	15.71**	3.55	6.01
Linear	(1)	64,418,740	186.11**	10,753,660	31.06**	4.41	8.28
Quadratic	(1)	4,455,705	12.87**	126,706	0.37	4.41	8.28
Nitrogen levels x Years	4	6,534,327	18.88**	617,940	1.78	2.93	4.58
Error a	18	346,123		346,272			

Varieties	1	14,019,572	90.19**	13,120,003	134.39**	3.89	6.76
Spacings	3	1,543,565	9.93**	938,712	9.62**	2.65	3.88
Linear	(1)	4,438,780	28.56**	2,787,136	28.55**	3.89	6.76
Quadratic	(1)	135,278	0.87	8,022	0.08	3.89	6.76
Cubic	(1)	56,638	0.36	20,976	0.21	3.89	6.76
Varieties x Spacings	3	292,291	1.88	56,593	0.58	2.65	3.88
Years x Varieties	2	242,355	1.56	115,571	1.18	3.04	4.71
Years x Spacings	6	425,480	2.74*	49,369	0.51	2.14	2.90
Nitrogen levels x Varieties	2	1,142,718	7.35**	19,133	0.20	3.04	4.71
Nitrogen levels x Spacings	6	132,564	0.85	158,524	1.62	2.14	2.90
Years x Nitrogen levels x Varieties	4	240,291	1.55	18,699	0.19	2.41	3.41
Years x Nitrogen levels x Spacings	12	162,976	1.05	55,686	0.57	1.82	2.30
Years x Varieties x Spacings	6	76,675	0.49	55,131	0.56	2.14	2.90
Nitrogen levels x Varieties x Spacings	6	244,277	1.57	39,364	0.40	2.14	2.90
Years x Nitrogen levels x Varieties x Spacings	12	134,290	0.86	29,854	0.31	1.82	2.30
Error b	189	155,442		97,629			

*Sighificant at 5% level. **Significant at 1% level.

Table 3. The plasticity of rice varieties in response to spacing, 1965-1967.

Variety	Crop season	Grain yield per hill (g)				Plasticity index		
		30× 5cm (A)	30×10cm (B)	30×15cm (C)	30×20cm (D)	B/A	C/A	D/A
Chianung 242	First crop	9.9	19.4	27.9	37.6	1.96	2.82	3.80
	Second crop	8.1	15.8	23.3	30.7	1.95	2.88	3.79
Tainan 3	First crop	10.5	20.7	30.9	39.9	1.97	2.94	3.80
	Second crop	8.9	17.6	25.7	33.3	1.98	2.89	3.74
Average of 2 varieties	First crop	10.2	20.1	29.4	38.8	1.97	2.88	3.80
	Second crop	8.5	16.7	24.5	32.0	1.96	2.88	3.76

Effect of Nitrogen Level on Grain Yield

Grain yield of rice were maximized when rice plants were given 160 kg of nitrogen per ha (Table 4). The average grain yields increased 889 and 1,212 kg per ha or 15.01 and 20.47% in the first crop, and 335 and 543 kg per ha or 6.43 and 10.43% in the second one

at 120 and 160 kg of nitrogen per ha, respectively. The response of grain yield to the increase of nitrogen was more pronounced in the first crop season. Differences of grain yield among nitrogen levels were significant at the 1% level in both crops (Table 2). However, the nature of response differed with crop seasons. In the first crop, the regression of grain yield on nitrogen level was parabolic in form, the rate of yield increase reducing more rapidly with the increase of nitrogen. The regression was essentially linear in the second crop, the rate of yield increase at different levels of nitrogen being almost the same.

Table 4. Grain yield and nitrogen response of 2 rice varieties, 1965-1967.

Variety	Nitrogen level (kg/ha)	Grain yield (kg/ha)		Nitrogen response (increase in kg/ha)		Nitrogen response (% increase)	
		First crop	Second crop	First crop	Second crop	First crp	Second crop
Chianung 242	80	5,808	4,965	—	—	—	—
	120	6,463	5,273	655	308	11.28	6.20
	160	6,893	5,485	1,085	520	18.68	10.47
Tainan 3	80	6,038	5,452	—	—	—	—
	120	7,159	5,813	1,121	361	18.57	6.62
	160	7,375	6,019	1,337	567	22.14	10.40
Average of 2 varieties	80	5,922	5,208	—	—	—	—
	120	6,811	5,543	889	335	15.01	6.43
	160	7,134	5,751	1,212	543	20.47	10.43

The nitrogen x year interaction was significant only in the first crop. This interaction was resulted largely from the poor nitrogen response in the first crop of 1967. There was also a highly significant nitrogen x variety interaction in the first crop. The grain yield of Tainan 3 showed a curvilinear response to the increase of nitrogen, but the response of Chianung 242 was essentially linear (Table 5). The grain yields of both varieties responded similarly to nitrogen in the second crop, thus accounting for the lack of a nitrogen x variety interaction. Both varieties generally produced better grain yields at the higher level of nitrogen in both crops of the years tested, since there were no significant year x nitrogen x variety interactions.

Table 5. Linear, quadratic and cubic comparisons for each variety in combined 1965-1967 data.

Treatment	Variety	Comparison	D.F.	Firs tcrop		Second crop		LSD	
				M. S.	F.	M. S.	F.	5%	1%
Nitrogen levels	Chianung 242	Linear	1	25,745,120	74.38**	4,898,325	14.15**	4.41	8.28
		Quadratic	1	370,653	1.07	26,354	0.08	4.41	8.28

	Tainan 3	Linear	1	39,396,900	113.82**	5,877,630	16.97**	4.41	8.28
		Quadratic	1	5,647,208	16.32**	116,323	0.33	4.41	8.28
Spacings	Chianung 242	Linear	1	2,461,482	15.84**	966,314	9.90**	3.89	6.76
		Quadratic	1	528,202	3.40	20,760	0.21	3.89	6.76
		Cubic	1	398,509	2.56	2,387	0.02	3.89	6.76
	Tainan 3	Linear	1	1,989,827	12.80**	1,898,820	19.45**	3.89	6.76
		Quadratic	1	42,694	0.27	73,306	0.75	3.89	6.76
		Cubic	1	86,854	0.56	24,325	0.25	3.89	6.76

**significant at 1% level.

Effect of Plant Spacing and Nitrogn Level on Grain yield

Varietal responses to spacing at each nitrogen level are shown in Figure 1. The grain yields of both varieties were higher at closer spacing at each nitrogen level in both crops with the following exceptions: lower yields of 30 x 10 and 30 x 5 cm spacings of Tainan 3 in the first crop and all 3 closer spacings of Chianung 242 in the second crop at the highest nitrogen level. As a result, closer spacings showed only limited yield advantage at 160 kg of nitrogen per ha in the second crop, when data were pooled over varieties.

Rice varieties generally produced highest yields at the highest nitrogen level at each spacing except 160 kg per ha of nitrogen at 30 x 5 cm spacing of Chianung 242 in the second crop (Figure 2). Consequently, average yields of 120 and 160 kg of nitrogen per ha were almost similar at 30 x 5 cm spacing in the second crop. Because of largely independent effects of nitrogen and spacing, nitrogen x spacing interactions were not significant in both crops.

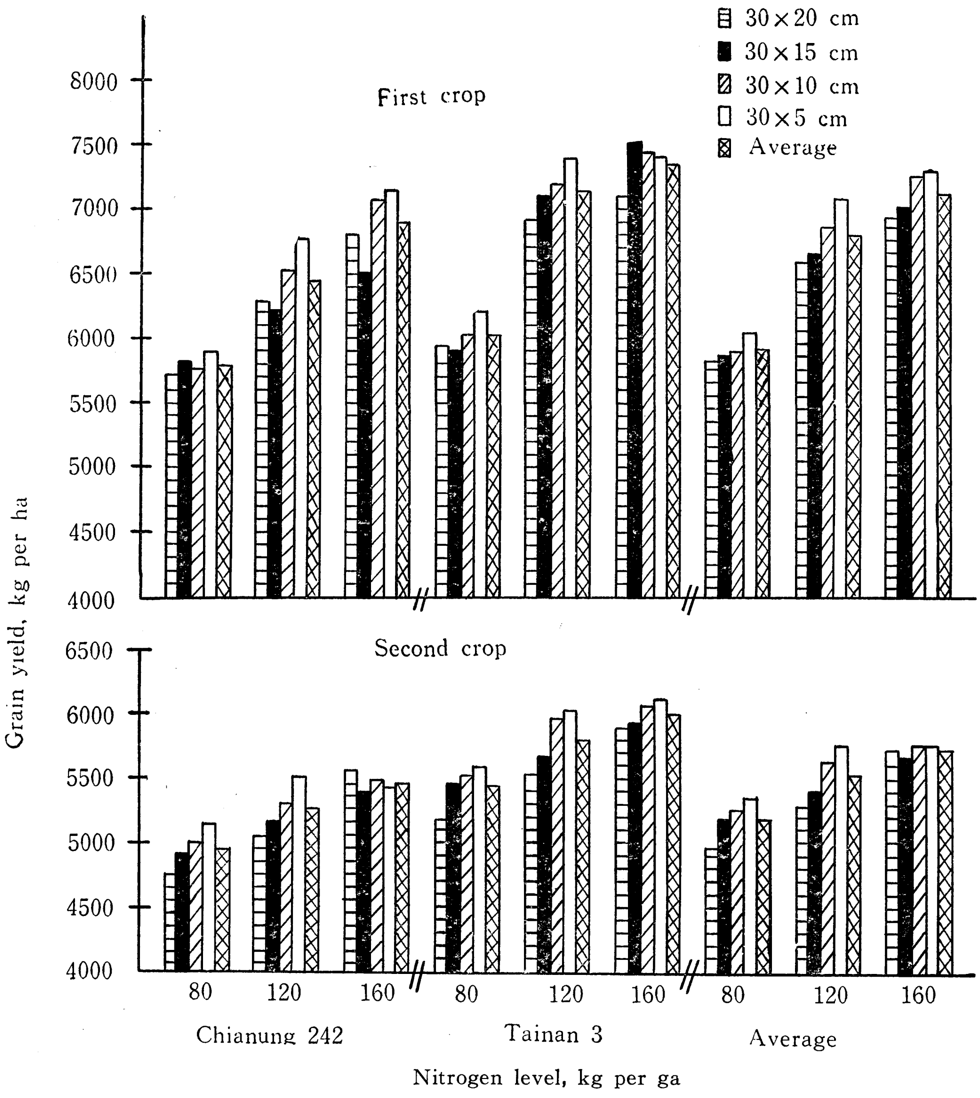

Figure 1. Yield response of 2 rice varieties to spacing at 3 levels of nitrogen, 1965-1967.

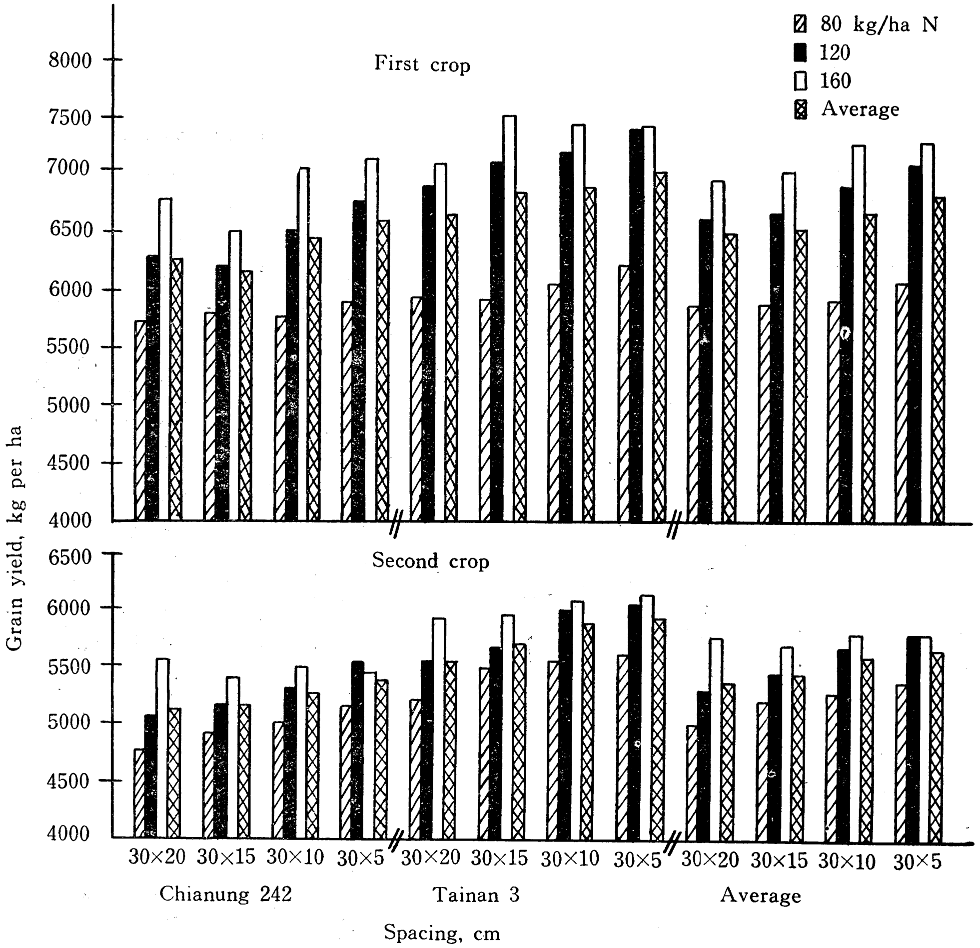

Figure 2. Yield response of 2 rice varieties to nitrogen level at 4 spacings, 1965-1967.

Multiple correlation coefficients (R) in Table 6 showed that nitrogen and spacing were possitively correlated with grain yield of rice. The correlations in the first crop were generally larger than those of the second one, although all correlations were significant at the 1% level. F values of multiple regression in the first crop were also considerably bigger than those of the second one. Coefficients of determination (R^2) showed that yield variations of about 40 and 21% in Chianung 242 and 43 and 17% in Tainan 3 could be ascribed to the joint effects of nitrogen and spacing in the first and the second crops, respectively.

Table 6. Multiple correlation coefficients, (R), coefficients of determination (R^2) and F values of multipliple regression of grain yield on nitrogen levels and spacings.

	Chianung 242		Tainan 3		Average of 2 varieties	
	First crop	Second crop	First crop	Second crop	First crop	Second crop
Multiple correlation coefficients (R)	0.6292**	0.4588**	0.6599**	0.4149**	0.6171**	0.3916**
Coefficients of determination (R^2)	0.3959	0.2105	0.4355	0.1721	0.3808	0.1534
F values of multiple regression	30.58**	12.44**	36.00**	9.70**	58.21**	17.15**

**significant at 1% level.

There were no significant year x nitrogen x spacing, variety x nitrogen x spacing, and year x variety x nitrogen x spacing interactions in both crops. Both varieties generally gave highest yields at close spacing and at the high nitrogen level during the years of the experiment.

Effect of Plant Spacing and Nitrogen Level on Compononts of Yield

Number of panicles per hill, number of grains per panicle, weight of 1,000 grains, and percentage of fertility of both varieties as influenced by spacing and nitrogen treatments are summarized in Table 7. The number of panicles per hill of both rice varieties increased with the increase of nitrogen but decreased quite drastically with the decrease of spacing in both crops. The number of grains per panicle also decreased with the decrease of spacing. However, the effect of nitrogen on the number of grains per panicle was rather irregular. In the first crop, it decreased slightly when nitrogen was raised from 80 to 120 kg per ha, but increased slightly when nitrogen was raised from 120 to 160 kg per ha. The response was similar in both varieties. In the second crop, the number of grains per panicle of Chianung 242 increased and that of Tainan 3 decreased with the increase of nitrogen. The changes, however, were rather small. Added nitrogen generally decreased 1,000-grain weight in the first crop, but increased it in the second one. The weight of 1,000 grains showed a slight increase with the decrease of spacing in both crops. The fertility percentage of both varieties also decreased with the increase of nitrogen and increased with the decrease of spacing in both crops.

Table 7. Mean values of yield components of 2 rice varieties grown at 4 spacings and 3 levels of nitrogen, 1965-1967.

Treatment	Number of panicles per hill		Number of panicles per 3.3m		Number of grains per panicle		Weight of 1,000 grains (g)		Fertility (%)	
	First crop	Second crop	First crop	Second crop	First crop	Second crop	First crop	Second crop	First crop	Second crop
Chianung 242										
Nitrogen										
80 kg/ha	9.4	7.2	882.5	676.4	131.0	145.8	29.6	29.2	97.3	92.2
120 kg/ha	10.4	7.5	978.8	722.7	126.4	148.6	29.3	29.4	93.4	91.2
160 kg/ha	11.4	8.5	1,068.0	803.8	128.8	149.6	28.9	29.6	92.8	90.6
Spacing										
30x20 cm	14.8	10.9	810.5	595.8	138.4	157.6	29.1	29.3	92.8	90.7
30x15 cm	12.3	9.0	894.1	656.4	131.6	149.5	29.1	29.5	92.9	90.9
30x10 cm	8.9	6.6	977.8	721.4	129.1	149.9	29.3	29.4	93.4	91.3
30x 5 cm	5.6	4.4	1,223.5	963.5	117.0	135.0	29.5	30.0	94.0	92.6
Tainan 3										
Nitrogen										
80 kg/ha	11.8	8.7	1,109.0	829.0	116.5	138.0	27.6	27.8	95.4	92.2
120 kg/ha	13.4	9.5	1,261.0	875.1	115.8	138.3	27.3	28.0	94.8	90.8
160 kg/ha	14.7	10.2	1,371.8	950.3	119.7	136.6	27.1	28.2	93.9	91.6
Spacing										
30x20 cm	19.2	13.3	1,053.9	708.8	123.7	146.3	27.2	27.8	94.3	92.2
30x15 cm	15.7	11.2	1,148.1	803.3	121.3	141.4	27.3	28.0	94.5	90.2
30x10 cm	11.1	8.2	1,215.8	895.3	117.7	133.9	27.4	28.1	94.7	91.7
30x 5 cm	7.2	5.1	1,571.2	1,131.8	107.7	129.0	27.7	28.1	95.2	92.1

Effect of Plant Spacing and Nitrogen Level on Leaf Area Index

The leaf area index (LAI) of Tainan 3 at the heading stage was larger than that of Chianung 242 in both crop seasons (Table 8). The LAI increased with the increase of nitrogen application and with a reduction in spacing. However, the degree of increase in LAI by nitrogen was considerably greater than that of spacing. The LAI in the first crop was also larger than that in the second crop. When averaged over varieties, LAI at the heading was generally correlated positively with grain yield of rice. The correlations in the first crop were not significant except that of 30 x 5 spacing which was significant at 5% level (Table 9). In the second crop, however, correlations were all significant at the 1% level except

those of 120 and 160 kg of nitrogen per ha which were significant at the 5% level. In the first crop, the correlation coefficients became smaller with the increase of nitrogen but were rather irregular in the spacing treatments. The degree of association between LAI and grain yield gegerally decreased with the increase of nitrogen and the reduction in spacing.

Table 8. Leaf area index (LAI) of 2 rice varieties grown at 4 spacings and 3 rates of nitrogen, 1966-1967.

	First crop			Second crop		
	Chianung 242	Tainan 3	Average of 2 varieties	Chianung 242	Tainan 3	Average of 2 varieties
Nitrogen						
80 kg/ha	4.64	5.08	4.86	3.38	3.87	3.36
120 kg/ha	5.05	6.19	5.62	4.03	4.64	4.34
160 kg/ha	5.95	7.44	6.70	4.48	5.21	4.85
Spacing						
30x20 cm	4.74	5.74	5.24	3.38	4.24	3.81
30x15 cm	5.24	6.24	5.74	3.72	4.41	4.07
30x10 cm	5.21	6.04	5.63	4.06	4.52	4.29
30x 5 cm	5.65	6.94	6.30	4.69	5.12	4.91

Table 9. Correlation coefficients between leaf area index and grain yield of rice 1965-1967.

	Nitrogen level (kg/ha)			Spacing (cm)			
	80	120	160	30x20	30x15	30x10	30x 5
First crop	0.1781	0.1293	– 0.0500	0.3627	0.0898	0.3540	0.4462*
Second crop	0.5080**	0.4462*	0.4136*	0.7398**	0.6044**	0.5980**	0.5154**

*significant at 5% level. The d.f. was 30 for nitrogen and 22 for spacing.

**significant at 1% level.

Effect of Plant Spacing and Nitrogen Level on Some Agronomic Traits

The effects of spacing and nitrogen on some agronomic characters of rice varieties Chianung 242 and Tainan 3 are presented in Table 10. Heading date tended to be delayed by the increase of nitrogen, but hastened by the reduction of spacing. Added nitrogen increased

plant height whereas reduced spacing decreased it. Panicle length was slightly increased by nitrogen and decreased by spacing. Panicle weight was not affected by the increase of nitrogen but decreased slightly with the reduction in spacing. High nitrogen level and close spacing generally resulted in the small grain-straw ratio. Both varieties responded similarly to spacing and nitrogen treatments in both crops.

Table 10. Mean values of some agromic traits of 2 rice varieties grown at 4 spacings and 3 levels of nitrogen, 1965-1967.

	Heading date		Plant beight		Panicle length		Panicle weight		Grain/straw	
	First crop	Second crop	First crop	Second crop	First crop	Second crop	First crop	Second crop	First crop	Second crop
					Chianung 242					
Nitrogen										
80 kg/ha	103.8	72.8	105.7	115.9	23.3	23.5	3.8	4.4	1.83	1.56
120 kg/ha	103.7	72.7	110.3	119.9	23.1	24.0	3.6	4.1	1.74	1.56
160 kg/ha	105.1	72.5	114.8	123.4	22.9	24.4	3.6	4.1	1.68	1.43
Spacing										
30x20 cm	104.7	72.7	113.5	121.8	23.6	24.1	3.9	3.9	1.85	1.56
30x15 cm	104.4	72.7	112.8	121.4	23.2	23.9	3.6	3.8	1.69	1.55
30x10 cm	103.9	72.7	109.3	119.9	23.1	24.0	3.6	3.7	1.74	1.50
30x 5 cm	103.8	72.7	105.4	115.8	22.9	23.9	3.4	3.8	1.72	1.44
					Tainan 3					
Nitrogen										
80 kg/ha	102.9	71.8	96.1	107.0	21.5	22.1	3.2	3.5	1.90	1.56
120 kg/ha	103.6	72.1	102.5	110.6	21.5	22.5	3.1	3.5	1.75	1.53
160 kg/ha	103.8	72.3	107.1	115.7	21.6	22.7	3.2	3.5	1.61	1.51
Spacing										
30x20 cm	103.3	72.4	104.5	112.9	21.8	22.7	3.3	3.8	1.87	1.57
30x15 cm	103.7	72.4	103.0	112.2	21.8	22.5	3.3	3.6	1.71	1.54
30x10 cm	103.3	71.9	100.9	110.7	21.4	22.3	3.1	3.4	1.62	1.51
30x 5 cm	103.5	71.5	98.4	108.7	21.0	22.1	2.9	3.3	1.66	1.38

DISCUSSION

The data generally indicated a yield advantage of close spacing and high nitrogen application. This is of great significance to rice production in Taiwan in view of the present

trend of rice cultivation in trying to obtain high yield through close spacing and heavy fertilization. Spacing and nitrogen are generally regarded as two important factors determing grain yield of rice (Matso, 1965). However, the effect of spacing was considerably smaller than that of nitrogen. It was observed that doubling the amount of nitrogen gained more than 20 and 10% yield increases in the first and the second crops respectively, whereas a four-fold reduction in spacing resulted in only a 5 % increase in grain yield in both crop seasons. The low density response of rice may be due to the following two factors: (1) Rice plants produced more panicles per hill at at wide spacing which partially compensated for decreased stand density at wide spacing. (2) The widest spacing of this experiment, 30 x 20 cm may be considered as a close spacing when compared with the existing planting density of 56-64 hills per 3.3 m^2 in Taiwan or an ordinary spacing, 30 x 30 cm, commonly adopted in the Southeast Asia (Kawano and Tanaka, 1968). Density response within close spacings is naturally limited in magnitude. Under the present circumstances, increase in nitrogen rather than reduction in spacing should be emphasized.

It is of interest to note that the grain yield of Chianung 242 responded linearly whereas that of Tainan 3, curvilinearly to the increase of nitrogen in the first crop, indicating that Chianung 242 has greater potentiality for yield increase at higher nitrogen level than Tainan 3. It was found that total nitrogen responses of Tainan 3 at nitrogen levels of 120 and 160 kg per ha were larger than those of Chianung 242. However, the net nitrogen response from medium to high nitrogen levels of Tainan 3 (3.57%) was less than half that of Chianung 242 (7.40%), showing that nitrogen level for maximum yield production is probably not far from 160 kg per ha with Tainan 3; with Chianung 242, however, continueous yield increase is highly likely even nitrogen exceeds substantially the level of 160 kg per ha. Chang (1967a) reported that Chanung 242 is more adaptable to higher level of fertility because it was developed under such environmental condition. Tanaka *et al.* (1964) also pointed out that some panicle weight type varieties respond well to heavy nitrogen because panicle number types suffer from mutual shading more seriously. With limited nitrogen application, however, panicle number types respond to nitrogen better than panicle weight types as reported by Baba (1961).

There were no significant varietal differences in density response in both crops. The plasticity indices of both varieties at various spacings were quite similar indicating that the capacity of Chianung 242 and Tainan 3 in response to spacing may be the same. Chang (1967b) has pointed out that present commercial Ponlai variaties of Taiwan are generally of typical panicle weight types in comparison with Japanese varieties which are mostly of panicle number types. Although Tainan 3 tillers slightly better than Chianung 242, the difference is apparently too small in magnitude to cause any significant change in varietal response to spacing. Takahashi (1944) reported that panicle weight types showed better density response than panicle number types. Tanaka (1965) suggested that a high yield will probably be obtained with a weak tillaring variety closely spaced. Yamameto and Toriyama (1968) also suggested that a heavy panicle type is considered to be a desirable plant type in the high planting density.

It was observed that the response of grain yield to the increase of nitrogen in the first

crop was nearly twice as high as that in the second crop. The result was similar to that of the previous report (Chang and Yang, 1965). Results of Tanaka *et al.* (1964) also indicated a greater nitrogen response in the dry than in the wet seasons. Seasonal difference in density response was, however, very slight. The coefficients of determination indicate that spacing and nitrogen could account for no more than 20% of the variation in grain yield in the second crop which may be largely responsible for the low yielding ability of the second crop in Taiwan. The average temperature during 1965–'67 was 23.6°C in the first crop and 27.1°C in the second one, whereas the mean sunshine hours during ripening were 3.7 and 3.9 hours per day in the first and the second crops, respectively. It appears, therefore, that the greater nitrogen response in the first crop may be attributable to the lower temperature of the first crop, and sunlight is probably not a major factor causing low nitrogen response in the second crop.

In the tropics, rice plants tiller actively in rainy season because of higher temperature. Since the tillers per unit area is the major component of leaf area index (Tanaka *et al.*, 1964), the increase in foliage produces serious mutual shading and adversely affects grain yield. The reduction of grain yield casued by mutual shading is greater with larger application of nitrogen or if solar radiation is smaller (Tanaka et al., 1966) As solar radiation is usually less during the rainy season in the tropics, the effects of close spacing and heavy nitrogen application are seriously affected. The situation in Taiwan is, however, quite different from that prevailing in the tropics. In the second crop, an equivalent of rainy season in the tropics, rice plants produce less tillers, resulting in smaller leaf area index. Since there is usually no shortage of light during ripening of the second crop, mutual shading is not a serions problem. This was fully confirmed by the highly significant correlations between leaf area index and grain yield in the second crop. Thus, poor performance of close spacing and heavy nitrogen application in the second crop arises primarily from insufficient growth of rice plants. The importance of plant type on the varietal response to spacing and nitrogen also can not be neglected (Jennings and Beachell, 1965; Matsuo, 1965; Yamamoto and Toriyama, 1968)

The analysis of yield component revealed that the increase in the number of panicles per unit area was the major factor contributing to the yield increase at close spacing and heavy application of nitrogen. The result well agreed with those of Chang and Yang (1964) and Hsieh *et al.* (1966), The number of panicles per 3.3 m^2 of Tainan 3 was considerably higher than that of Chianung 242 which may be the main source of varietal difference in yielding ability at each treatment. Rice plants were taller in the second crop especially in the close spacing with heavy nitrogen application, suggesting that lodging is a problem in the second crop because plant height is negatively correlated with lodging resistance factor (Chang, 1967). Thus, lower yields of close spacings at highest nitrogen level of 160 kg per ha may be largely attributable to lodging. As lodging affects grain yield markedly (Jennings and Sornchai, 1964), every possible effort should be exerted to reduce its damage when rice is grown at close spacing with heavy nitrogen. Dense planting with "wide-row and close-hill spacing" offers an effective solution to this problem since wide-row spacing is likely to increase the absorption of incoming solar radiation, resulting in thicker and stronger culms to reduce lodging. Hsieh *et al.* (1966) also reported that the rectangular form of planting is

better in the second crop.

Based on the result of this experiment, the optimum levels of spacing and nitrogen for maximum yield production apper to be 30 x 5 cm spacing with 160 kg per ha of nitrogen and 30 x 5 cm spacing with 120 kg per ha of nitrogen for Chianung 242 or varieties of the similar plant type in the first and the second crops, respectively. For Tainan 3 or varieties like it, 30 x 15 cm spacing with 160 kg per ha of nitrogen in the first crop, and 30 x 5 cm spacing with 160 kg per ha of nitrogen in the second one may be the best combinations. From the average performance of these two varieties, a general conclusion seems to be that when the present commercial Ponlai varieties are used, 30 x 10 cm spacing with nitrogen application of 160 kg per ha and 30 x 5 cm spacing with 120 kg per ha of nitrogen are likely to yield best in the frist and the second crops,respectively. The difficulty of transplanting at close spacing can be easily solved when the transplanting machine or direct seeding method are successfully released for general use. The spacing and nitrogen responses can also be improved when new rice varieties with more desirable plant type become available. By a more efficient combination of cultural techniques and rice varieties, it is highly likely that rice production with close spacing and heavy application of nitrogen can be greatly stabilized in the near future.

SUMMARY

The responses of two *japonica* rice varieties, Chianung 242 and Tainan 3, to four spacings and three levels of nitrogen were studied over a 3-year period from 1965 to 1967 at Tai-tou-ken Farm of the Chiayi Agricultural Experiment Station.

Grain yields increased with the reduction of spacing and the increase of nitrogen which was more pronounced in the first crop of rice. The effects of plant spacings and nitrogen levels on grain yields were all significant at the 1% level of probability in both crops. Chianung 242 responded linearly and Tainan 3, curvilinearly to nitrogen in the first crop whereas in the second crop, both varieties showed linear response to nitrogen. The regression of grain yield to spacing was essentially linear in both crops and both varieties responded similarly. Coefficients of determination showed that about 40 and 20% of grain yield variations could be ascribed to the effects of spacing and nitrogen in the first and the second crops, respectively.

The number of panicles per hill and the number of grains per panicle decreased whereas the weight of 1,000 grains and the percentage of fertility increased with the reduction of spacing in both crops. The response was similar in both varieties. The number of panicles per hill increased and the percentage of fertility decreased with the increase of nitrogen. No differences in varietal response were observed in both crop seasons. The number of grains per panicle of Chianung 242 increased in the first crop and decreased in the second one with the increase of nitrogen, but Tainan 3 responded just in the opposite way. The weight of 1,000 grains of both varieties increased in the first crop and decreased in the second one with the increase of nitrogen. The number of panicles per unit area of both varieties increased with the reduction of spacing and increased with the increase of nitrogen.

Leaf area index of both varieties generally increased with the decrease of spacing and with the increase of nitrogen. Rice plants generally showed larger leaf area index in the first crop. Leaf area index was, however, more closely associated with grain yield in the second

crop.

Heading date was delayed by the increase of nitrogen but was hastened by the decrease of spacing. plant panicle weight was not affected by nitrogen but decreased slightly with the reduction of spacing. Grain-straw ratio decreased with the increase of nitrogen and the reduction of spacing. Both varieties responded similarly in both crops.

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水稻品種對栽植密度及氮素肥料之效應

張 萬 來

中 文 摘 要

本文係報告嘉義農業試驗分所自民國54年第1期作起至56年第2期作承辦全省性水稻寬行密植試驗之綜合報告。

栽植密度及氮素肥料之提高均能導致稻谷之增產，其效果在第1、2期作均極爲顯著，水稻品種在第1、2期作對栽植密度均顯示直線效應，惟對肥料效應則因品種及期作而異。在第1期作，嘉農242號顯示直線效應而臺南3號則爲曲線效應，在第2期作，兩品種之肥料效應均爲直線關係。由決定係數可知栽植密度及氮素肥料分別在第1、2期作決定大約40及20%之產量變異。

每株穗數及每穗粒數因密植而低減而千粒重及稔實率則因密植而增加。兩品種在第1、2期作之反應均同，水稻品種之每株穗數與稔實率在第1、2期作均因氮素之增施而增加，嘉農242號之每穗粒數在第1期作因增加氮素肥料而增加，第2期作則因氮素肥料之增加而減少，臺南3號之反應則與嘉農242號恰恰相反。兩品種之千粒重在第1期作則因增肥而增加，但在第2期作則因增肥而減低，每坪穗數均因增肥密植而增多。

葉面積指數大致隨增肥密植而加大，水稻之葉面積指數在第1期作較大，但其與稻谷產量之關係則以第2期作者爲密切。

生育日數因增肥而延長，而因密植而縮短，穗長受肥料影響較微，惟因密植而稍減，谷草比亦因增肥密植而低減。水稻品種在第1、2期作之反應大致相同。